Impact responses of highspeed railway track slabs

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Impact Responses of the Highspeed Railway Track Slabs

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Abstract. Impact loads pose a lot of hazards including causing severe damage to both railcars and rail track components, for example, cracking of slabs or sleepers. The impact loads can be as a result of several factors including flat spots on rail wheels attributed to the train braking, dipped rails, rail squats, corrugation, crossing transfers, etc. The impact loads are often over a short duration but of very high magnitude. For instance, the typical loading duration produced by wheel flats is about 1-10 milliseconds, while the force magnitude can be over 400 kN per rail seat. This paper highlights an investigation into the behaviour of a slab-track subjected to impact loading. A parametric study has been carried out using the finite element analysis software, Strand7, to investigate the behaviour of slab-track under the action of the impact loading conditions. This was done by analysing the ratio of maximum impact moment to maximum static force under varying slab support conditions. The outcome of this study will potentially lead to a better understanding and hence, the design of slab track systems in highspeed railway tracks subjected to the impact loading. Our study revealed that for a slab-track under the action of impact loading, the slab-track is more sensitive to changes in the support stiffness at midspan than at the rail seats and effects of increasing or reducing support stiffness are more significant at these locations.

1. Introduction

High-speed rail is presently rapidly expanding mainly in Asia and Europe with Japan being effectively credited as being the birthplace of high-speed rail in Asia and France in Europe. The Japanese network comprises mainly of slab track and most slab track systems have very similar configurations (figure 1), consisting of a prefabricated precast slab track, a cast in place concrete roadbed and an intermediate cushion layer referred to as cement asphalt mortar (CAM) whose mechanical properties are greatly influenced by loading rate and temperature [1, 2].

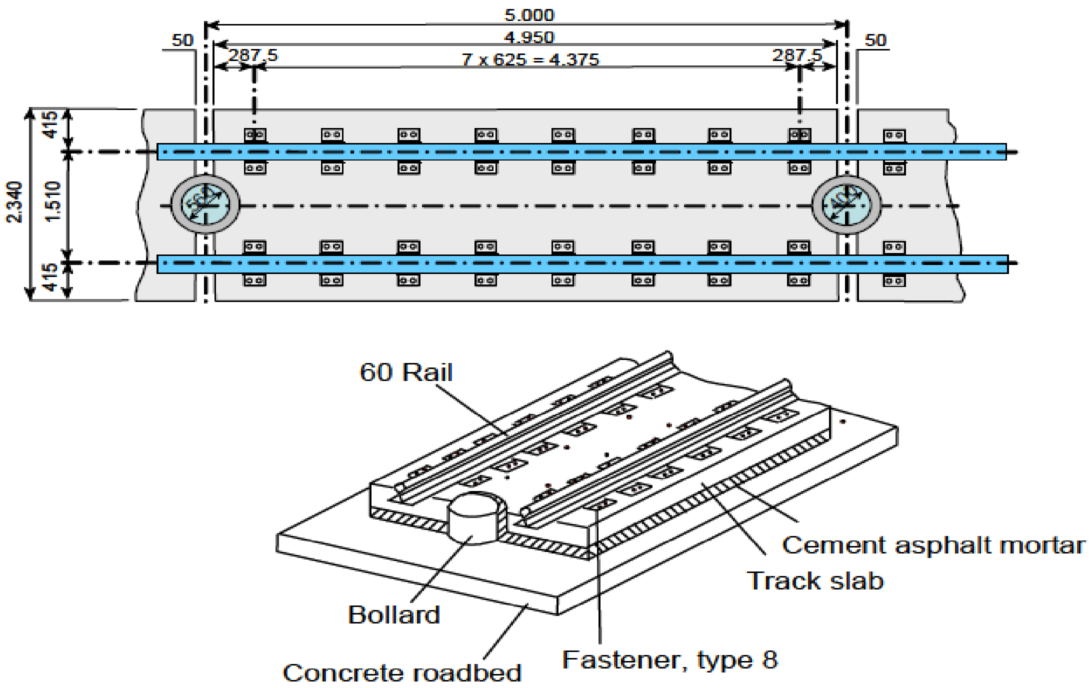

Figure 1. Typical Slab Track [3]

The forces that act on track components are often difficult to quantify, generally unevenly distributed and characterized by rapid fluctuations. They can either be quasi-static as a result of gross tare, centrifugal forces and crosswinds or dynamic as a result of track irregularities, discontinuities at welds, switches and joints as well as vehicle defects such as natural vibrations, hunting and wheel flats [3]. Railway track loading, especially in high-speed rail, is often very complex and recent studies have revealed that loading on railway track structures is predominantly dynamic, instead of static or quasi-static as often used in design [4]. Impact loads can be as a result of several factors including flat spots on rail wheels caused often by train braking, dipped rails, rail squats, corrugation, crossing transfers, etc. However, despite the many causes of impact loads, by far the largest dynamic loads applied to railway track structures are those that arise as a result of irregularities on vehicle wheels such as wheel flats [4]. The high forces resulting from such irregularities contribute significantly to track damage and ride discomfort.

A typical loading duration produced by wheel flats last anywhere between 1 and 10 milliseconds, however, the force magnitude can be amplified to over 400 kN per rail seat [3]. Research has shown that although slab tracks applications have improved, one of their disadvantages which still remains is that they tend to experience premature structural damage caused by a number of factors, including impact loading [5].

A lot of research has been done to investigate the railway sleepers' behaviour subjected to impact loading. From our knowledge, the nonlinear flexural analysis to investigate the effect of support stiffness on the maximum impact moment, $M_{max\text{-}impact}$ resulting from the application of impact force over the maximum static moment, $M_{max\text{-}static}$ resulting from the static application of force ratio, i.e. $M_{max\text{-}impact}$ / $M_{max\text{-}static}$ has not been investigated. As such, the objective of this study is to investigate how slab support stiffness affects the ratio of maximum moment resulting from impact loads to maximum moment resulting from the static loads. The starting value used for slab support stiffness was 2000N/mm/mm obtained from our experiments and this was varied by 10% decrements and increments.

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2. Finite element modelling

Many researchers have found the use of the two-dimensional Timoshenko beam model to be very useful and suitable in the modelling of railway concrete sleepers [6]. In this research study, a finite element model of the slab track has been developed using the finite element modelling software, Strand7. To take into account the slab's shear and flexural deformations and due to the nature of our slab which has a cross-sectional area of 600mm by 180mm and a length of 3000mm, it has been modelled as a beam element. The rail pads at rail seats and rails have been modelled as spring elements. To simulate the slab support conditions, this study uses the non-linear tensionless beam support feature found in Strand7 software [6]. Figure 2 below shows the finite element model of the slab which has been used in the analysis.

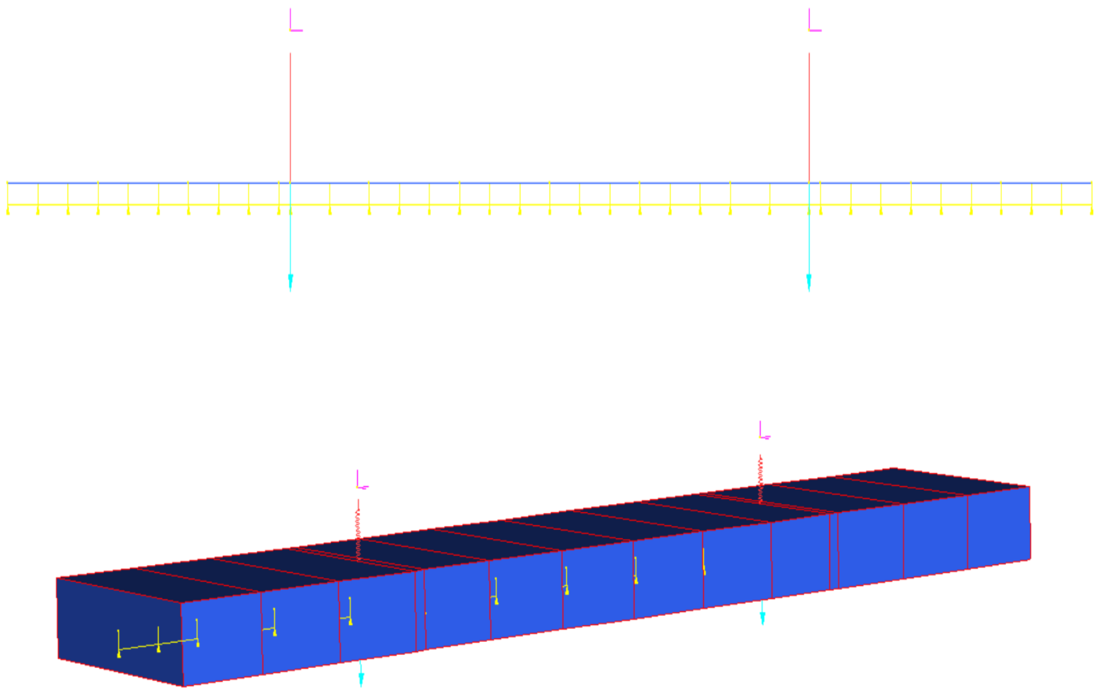

Figure 2. Finite element model of the slab

The effect of support stiffness on the ratio of maximum impact moment, $M_{max\text{-}impact}$ resulting from the application of impact force to the maximum static moment, $M_{max\text{-}static}$ resulting from the static application of force ratio, i.e. $M_{max\text{-}impact}$ / $M_{max\text{-}static}$ is investigated.

2.1. Quasi-static behaviour

Figure 3 below shows the shape of the bending moment diagram along the length of the slab when equal wheel loads of 100kN are applied on both wheels. From figure 3 below it is clear that the hogging (negative) and sagging (positive) moments are associated with midspan and rail-seat locations respectively. The magnitude of the bending moment depends on both the magnitude of the applied wheel loads as well as support stiffness conditions.

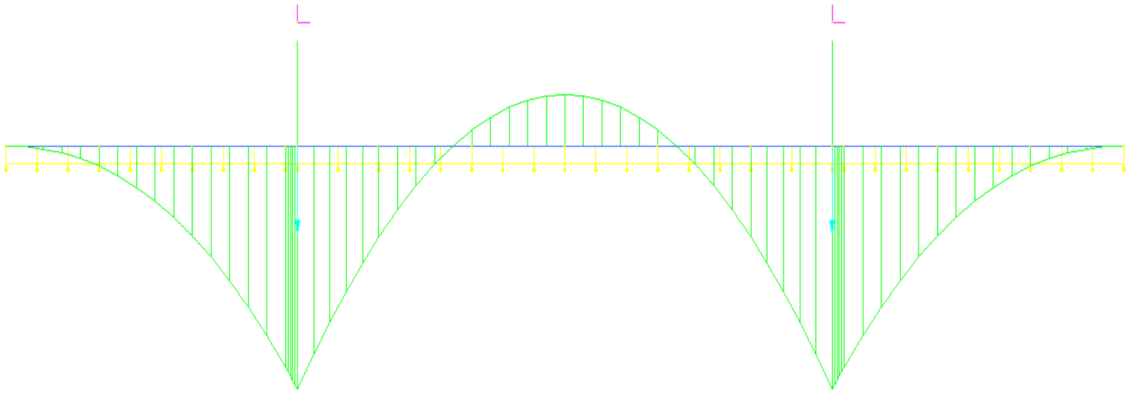

Figure 3. Typical bending moment diagram based Quasi-static loading

2.2. Impact or dynamic behaviour

Impact loading has been applied using the factor versus time method on the Strand7 software package where dynamic loads applied to the model are factored through the use of factor vs time tables. Figure 4 below shows the typical variation of bending moment with time at different locations when the impact load is applied.

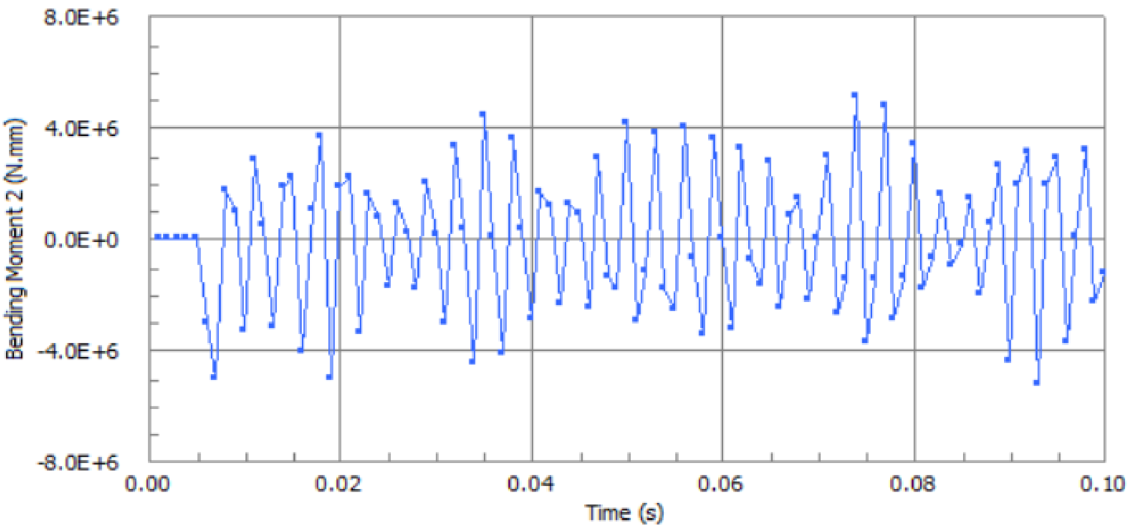

Figure 4. Variation of bending moment with time upon application of the impact force

3. Results and discussions

After investigating the effect of support stiffness, k on the ratio of maximum impact moment, $M_{max\text{-}impact}$ resulting from the application of impact force to the maximum static moment, $M_{max\text{-}static}$ resulting from the static application of force, i.e. $M_{max\text{-}impact} / M_{max\text{-}static}$ at both midspan and rail seat the following results were obtained.

According to the results in figures 5 and 6, it is clear that at both midspan and rail seat as the slab support stiffness increases, it results in the general increase of the $M_{max\text{-}impact} / M_{max\text{-}static}$ ratio. This means that as the slab support stiffness increases, the effects of impact force become more and more significant as compared to the static force. Comparing the two graphs, i.e. variation of $M_{max\text{-}impact} / M_{max\text{-}static}$ ratios with support stiffness at midspan and at the rail seat, it is evident from the gradients of the trendlines that the midspan has a steeper gradient. This means that the slab is more sensitive to changes in support stiffness at midspan than at rail seats and the effects of increasing support stiffness are more significant. For example, an increase of support stiffness from 1000N/mm/mm to 2600N/mm/mm results in the $M_{max\text{-}impact}$ / $M_{max\text{-}static}$ ratio increasing from 2.4 to 3.5, i.e. an increase of nearly 50% in the dynamic moment relative to the static moment.

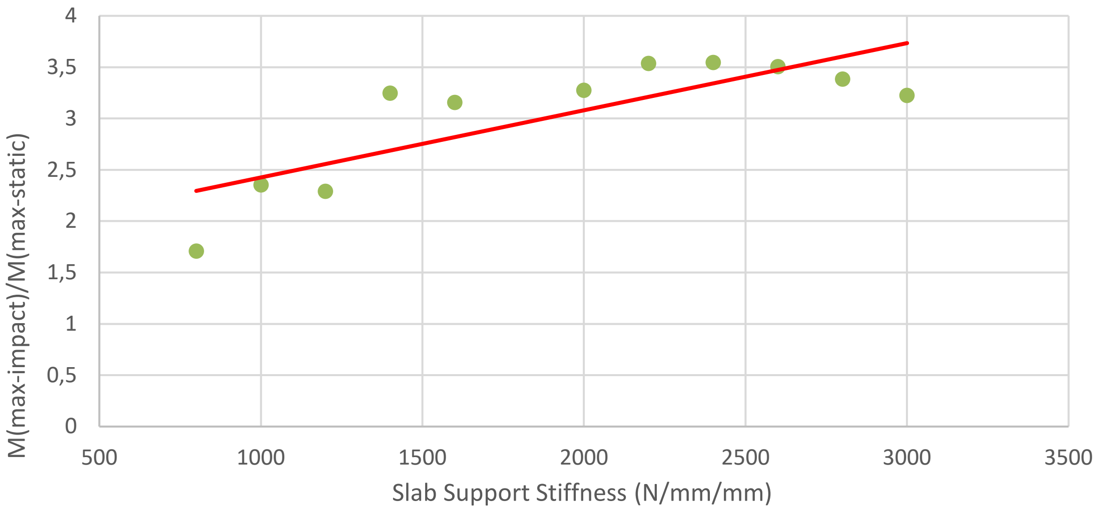

Figure 5. Variation of $M_{max\text{-}impact}$ / $M_{max\text{-}static}$ ratio with slab support stiffness at midspan

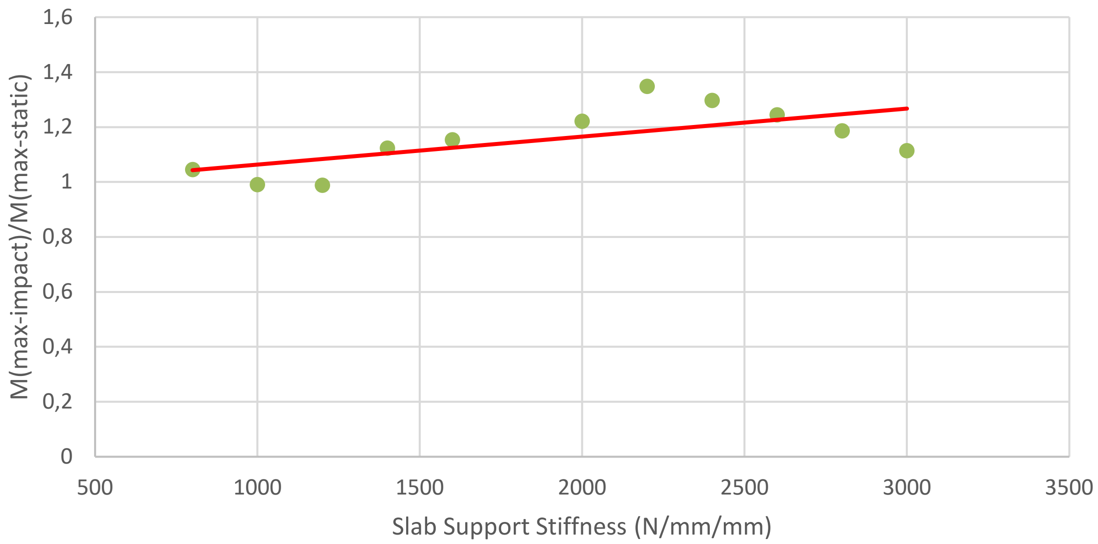

Figure 6. Variation of $M_{max\text{-}impact}$ / $M_{max\text{-}static}$ ratio with slab support stiffness at rail seat

4. Conclusions

This investigation clearly demonstrates the immense effects of the slab support stiffness on the dynamic moment over the static moment ratio. The results also demonstrate that generally, our slab track is more sensitive to the changes in the support stiffness at midspan than at rail seats. The outcome of this study will potentially lead to a better understanding and hence, the design of the slab track systems in highspeed railway tracks subjected to the impact loading.

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